interest when he has arrived so far, give up the further pursuit of scientific work. When the governors of any institution can bring men up to this point, and can then supply them with the necessary means, they may consider that their work is finished.

CLERK-MAXWELL'S ELECTRICITY AND MAGNETISM

A Treatise on Electricity and Magnetism. By James Clerk-Maxwell, M.A., F.R.S., Professor of Experimental Physics in the University of Cambridge. (Clarendon Press Series, Macmillan & Co., 1873.)

IN his deservedly celebrated treatise on "Sound," the late Sir John Herschel felt himself justified in saying, "It is vain to conceal the melancholy truth. We are fast dropping behind. In Mathematics we have long since drawn the rein and given over a hopeless race." Thanks to Herschel himself, and others, the reproach, if perhaps *then* just, did not long remain so. Even in pure mathematics, a subject which till lately has not been much attended to in Britain, except by a few scattered specialists, we stand at this moment at the very least on a par with the *élite* of the enormously disproportionate remainder of the world. The discoveries of Boole and Hamilton, of Cayley and Sylvester, extend into limitless regions of abstract thought, of which they are as yet the sole explorers. In applied mathematics no living men stand higher than Adams, Stokes, and W. Thomson. Any one of these names alone would assure our position in the face of the world as regards triumphs already won in the grandest struggles of the human intellect. But the men of the next generation—the successors of these long-proved knights—are beginning to win their spurs, and among them there is none of greater promise than Clerk-Maxwell. He has already, as the first holder of the new chair of Experimental Science in Cambridge, given the post a name which requires only the stamp of antiquity to raise it almost to the level of that of Newton. And among the numerous services he has done to science, even taking account of his exceedingly remarkable treatise on "Heat," the present volumes must be regarded as pre-eminent.

We meet with three sharply-defined classes of writers on scientific subjects (and the classification extends to all such subjects, whether mathematical or not). There are, of course, various less-defined classes, occupying intermediate positions.

First, and most easily disposed of, are the men of calm, serene, Olympian self-consciousness of power, those upon whom argument produces no effect, and whose grandeur cannot stoop to the degradation of experiment! These are the *à priori* reasoners, the metaphysicians, and the *Paradoxers* of De Morgan.

Then there is the large class, of comparatively modern growth, with a certain amount of knowledge and ability, diluted copiously with self-esteem—haunted, however, by a dim consciousness that they are only popularly famous —and consequently straining every nerve to keep themselves in the focus of the public gaze. These, also, are usually, men of "paper" science, kid-gloved and black-coated—with no speck but of ink.

Finally, the man of real power, though (to all seeming) perfectly unconscious of it—who goes straight to his mark with irresistible force, but neither fuss nor hurry—reminding one of some gigantic but noiseless "crocodile," or punching engine, rather than of a mere human being.

The treatise we have undertaken to review shows us, from the very first pages, that it is the work of a typical specimen of the third of these classes. Nothing is asserted without the reasons for its reception as truth being fully supplied—there is no parade of the immense value of even the really great steps the author has made—no attempt at sensational writing when a difficulty has to be met; when necessary, there is a plain confession of ignorance without the too common accompaniment of a sickening mock-modesty. We could easily point to whole treatises (some of them in many volumes) still accepted as standard works, in which there is not (throughout) a tithe of the originality or exhaustiveness to be found in any one of Maxwell's chapters.

The main object of the work, besides teaching the experimental facts of electricity and magnetism, is everywhere clearly indicated—it is simply to upset completely the notion of *action at a distance.* Everyone knows, or at least ought to know, that Newton considered that no one who was capable of reasoning at all on physical subjects could admit such an absurdity: and that he very vigorously expressed this opinion. The same negation appears prominently as the guiding consideration in the whole of Faraday's splendid electrical researches, to which Maxwell throughout his work expresses his great obligations. The ordinary form of statement of Newton's law of gravitation seems directly to imply this action at a distance; and thus it was natural that Coulomb, in stating his experimental results as to the laws of electric and magnetic action which he discovered, as well as Ampère in describing those of his electro-dynamic action, should state them in a form as nearly as possible analogous to that commonly employed for gravitation.

The researches of Poisson, Gauss, &c., contributed to strengthen the tendency to such modes of representing the phenomena; and this tendency may be said to have culminated with the exceedingly remarkable theory of electric action proposed by Weber.

All these very splendid investigations were, however, rapidly leading philosophers away towards what we cannot possibly admit to be even a bare representation of the truth. It is mainly to Faraday and W. Thomson that we owe our recall to more physically sound, and mathematically more complex, at least, if not more beautiful, representations. The analogy pointed out by Thomson between a stationary distribution of temperature in a conducting solid, and a statical distribution of electric potential in a non-conductor, showed at once how results absolutely identical in law and in numerical relations, could be deduced alike from the assumed distance-action of electric particles, and from the contact-passage of heat from element to element of the same conductor.

But we must give Maxwell's own frank and ample acknowledgment of his debt to these two men.

"The general complexion of the treatise differs considerably from that of several excellent electrical works, published, most of them, in Germany, and it may appear that scant justice is done to the speculations of several eminent electricians and mathematicians. One reason of this is that before I began the study of electricity I resolved to read no mathematics on the subject till I had first read through Faraday's 'Experimental Researches on Electricity.' I was aware that there was supposed to be a difference between Faraday's way of conceiving phenomena and that of the mathematicians, so that neither he nor they were satisfied with each other's language. I had also the conviction that this discrepancy did not arise from either party being wrong. I was first convinced of this by Sir William Thomson, to whose advice and assistance, as well as to his published papers, I owe most of what I have learned on the subject.

"As I proceeded with the study of Faraday, I perceived that his method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. I also found that these methods were capable of being expressed in the ordinary mathematical forms, and thus compared with those of the professed mathematicians.

"For instance, Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance: Faraday saw a medium where they saw nothing but distance: Faraday sought the seat of the phenomena in real actions going on in the medium, they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids."

It certainly appears, at least at first sight, and in comparison with the excessively simple distance action, a very formidable problem indeed to investigate the laws of the propagation of electric or magnetic disturbance in a medium. And Maxwell did not soon, or easily, arrive at the solution he now gives us. It is well-nigh twenty years since he first gave to the Cambridge Philosophical Society his paper on *Faraday's Lines of Force*, in which he used (instead of Thomson's heat-analogy) the analogy of an imaginary incompressible liquid, without either inertia or internal friction, subject, however, to friction against space, and to creation and annihilation at certain sources and sinks. The velocity-potential in such an imaginary fluid is subject to exactly the same conditions as the temperature in a conducting solid, or the potential in space outside an electrified system. In fact the so-called equation of continuity coincides in form with what is usually called Laplace's equation. In this paper Maxwell gave, we believe for the first time, the mathematical expression of Faraday's *Electro-tonic* state, and greatly simplified the solution of many important electrical problems. Since that time he has been gradually developing a still firmer hold of the subject, and he now gives us, in a carefully methodised form, the results of his long-continued study.

A sentence like the following has a most cheering effect when we meet with it in a preface; and we need only add that our author has been thoroughly successful in the endeavour he promised :—

"I shall avoid, as much as I can, those questions which, though they have elicited the skill of mathematicians, have not enlarged our knowledge of science."

He might with truth, and with propriety, have added that he would also avoid, as far as possible, those so-called experimental illustrations which require in the operator training akin to that of a juggler, and which are calculated to mystify, and to retard the progress of, the real student, while gratifying none but the mere gaping sight-seer.

It is quite impossible in such a brief notice as this to enumerate more than a very few of the many grand and valuable additions to our knowledge which these volumes contain. Their author has, as it were, flown at everything;—and, with immense spread of wing and power of beak, he has hunted down his victims in all quarters, and from each has extracted something new and invigorating —for the intellectual nourishment of us, his readers.

The following points, however, appear to us to be especially (we had almost said exceptionally) worthy of notice :—

1. Though not employing the Quaternion *Calculus*, Maxwell recognises its exceeding usefulness in exhibiting (merely by the extraordinary simplicity and comprehensiveness of its notation) the mutual relations of various directed, or vector, quantities; together with their derivation from scalar quantities, such as potentials, by the use of the Hamiltonian ∇, the operator whose square is the negative of the scalar operator in Laplace's equation. There can be little doubt that in this direction must lie the next grand simplification of the somewhat complex mathematics of electro-dynamic investigations.

2. The notion of electric *Inertia*, first clearly pointed out by Helmholtz and Thomson, is here developed in a most splendid style. The mechanism whose inertia has to be overcome before a steady current of electricity can be started or stopped in a conductor, and which opposes a resistance exactly analogous to the inertia equivalent of an ordinary train of wheels, is treated by means of the general equations of motion in the forms given respectively by Lagrange and by Hamilton. Maxwell has adopted from Thomson and Tait's "Natural Philosophy" the idea of commencing with the impulse required to produce a given motion of a system, and has developed in this way the general equations in a form suitable for electric problems where the mechanism is as yet entirely unknown.

3. The chapter dealing with *Electrolysis* we may specially refer to, as containing, not merely an admirable summary of what was previously known but also, several new ideas apparently of great value.

4. Another curious feature of the work is the amount of labour bestowed upon the exceedingly useful, but dry and uninteresting, pursuit of accuracy in the tracing of the forms of *Lines of Force* and determinations of strengths of electric and electro-magnetic fields, and their deviation from uniformity under various conditions, some of excessive complexity. For the theory of the newer instruments, especially Thomson's electrometers and galvanometers, and also for their applicability to problems in quite different branches of physics, these results are very valuable.

5. Another feature in which this differs from all but a very few of the very best scientific works is the particular care bestowed upon the modes of measurement, the units employed, and the *Dimensions* (in terms of these units) of the various quantities treated of—such as, for instance, Electric Quantity, Electric Potential, Electric Current, Electric Displacement, &c.

6. The subject of *Electric Images* is developed at considerable length, and the reader is led up by easy steps to a sketch of the grand problem which, though solved in simple finite terms a quarter of a century ago by Thomson, has remained unnoticed till very recently, viz., the statical distribution of electricity upon a spherical bowl.

7. The subject of *Spherical Harmonics* (Laplace's coefficients) is also treated at some length, and in a somewhat novel way, which leads to one of the quaternion methods of attack though without actually employing that calculus itself.

8. Further, there is given, for the first time, the complete solution of the problem of *Induction of Currents* in a disc rotating in the magnetic field, taking account of the mutual action of the currents on one another—a condition which very materially increases the difficulty of the problem. The result is a very curious one; and it appears especially curious when we compare the very simple, almost homely, methods employed by Maxwell with the elaborate analysis by means of which Jochmann and others, some years ago, attacked the incomplete and (comparatively) easy statement of the problem where the mutual action of the currents is not taken account of. This piece of work is worthy of being placed beside that of Thomson, referred to under (6) above, as among the very best things ever done in Mathematical Physics.

9. The ratio of the electro-magnetic to the electrostatic unit of electricity is a *Velocity* whose absolute value is independent of the magnitude of the fundamental units employed. This has been shown by Maxwell to be the velocity with which waves of transverse vibration will be propagated in the medium whose stresses &c. account on his theory for the apparent action at a distance. Neither the velocity of light in free space, nor the ratio of the electric units, is *certainly* known as yet within five or six per cent., but it is assuredly a most striking fact that (in millions of metres per second) three of the best determinations of the former of these quantities give

314, 308, 298,

while apparently equally good determinations of the latter give

311, 288, 282.

Such approximation is evidently much more than a mere fortuitous coincidence, it shows that a great step has been taken in the grand question of the connection between radiation and electrical phenomena.

Having said so much in hearty admiration of this noble work, a work which will do more to raise our country in the eyes of really competent judges than cartloads of more pretentious publications, it is only natural to seek some of its defects. There are spots on every sun; and they are, as phenomena, sometimes more instructive and therefore more worthy of observation than the sun itself. But, as they are not visible save to those whose eyes can bear the full glare of the glowing orb, and who therefore do not require our aid, it is unnecessary to point them out. Such a proceeding would be mere pandering to that miserable form of envy which leads inferior minds to gloat over the defects of their superiors.

The concluding section of the work is particularly well fitted to terminate our article.

> "We have seen that the mathematical expressions for electrodynamic action led, in the mind of Gauss, to the conviction that a theory of the propagation of electric action in time would be found to be the very keystone of electrodynamics. Now we are unable to conceive of propagation in time, except either as the flight of a material substance through space, or as the propagation of a condition of motion or stress in a medium already existing in space. In the theory of Neumann, the mathematical conception called Potential, which we are unable to conceive as a material substance, is supposed to be projected from one particle to another, in a manner which is quite independent of a medium, and which, as Neumann has himself pointed out, is extremely different from that of the propagation of light. In the theories of Riemann and Betti it would appear that the action is supposed to be propagated in a manner somewhat more similar to that of light.
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> "But in all of these theories the question naturally occurs:—If something is transmitted from one particle to another at a distance, what is its condition after it has left the one particle and before it has reached the other? If this something is the potential energy of the two particles, as in Neumann's theory, how are we to conceive this energy as existing in a point of space, coinciding neither with the one particle nor with the other? In fact, whenever energy is transmitted from one body to another in time, there must be a medium or substance in which the energy exists after it leaves one body and before it reaches the other, for energy, as Torricelli* remarked, 'is a quintessence of so subtle a nature that it cannot be contained in any vessel except the inmost substance of material things.' Hence all these theories lead to the conception of a medium in which the propagation takes place, and if we admit this medium as an hypothesis, I think it ought to occupy a prominent place in our investigations, and that we ought to endeavour to construct a mental representation of all the details of action, and this has been my constant aim in this treatise."

OUR BOOK SHELF

Medizinische Jahrbücher Herausgegeben, Von der K. K. Gesellschaft der Aerzte redigert von S. Stricker. Jahrgang 1872. Hefte i. ii. iii. iv., pp. 513; mit xii. Tafeln.

THE second volume of Stricker's *Medizinische Jahrbücher*, now before us, maintains the promise of the first. It is made up of a number of separate essays on various subjects, physiological, pathological, and medical; the physiological essays predominating over the others.

Amongst these the following deserve notice.

1. Researches on the heart and blood-vessels, by Dr. Sigismund Mayer. In this paper Dr. Mayer shows that the extraordinary increase of pressure of the blood against the walls of the blood-vessels which occurs as a result of the administration of strychnia is due to intense excitation of the vaso-motor centre in the brain, which leads to contraction of the small arteries.

2. A paper by Ewald Hering on the influence of the respiration upon the circulation. In this he shows that moderate expansion of the lungs by insufflation causes diminished blood pressure in the arteries and increased rapidity of the heart's action. This latter effect, however, is not due to the increased pressure exerted upon the external surface of the heart, nor to alterations in the conditions of resistance in the circulation; nor to differences in the exchange of gases; nor to any dislocation of the heart's position, but is effected reflectorially through the pneumogastrics in such a manner that the activity of the cerebral centre of the inhibitory nerves is lowered.

3. MM. Oser and Schlesinger give the details, in an elaborate essay, of many experiments they have made to determine the causation of the movements of the uterus, and state that they have arrived at the conclusion that these movements can be induced by suspension of the respiration; by rapid loss of blood; or by arrest of the supply of arterial blood to the brain.

4. M. M. Rosenthal contributes an interesting essay on the death of the muscles of the body, and on apparent death. He made many experiments on about twenty sub-

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* *Lezioni Accademiche* (Firenze, 1715), p. 25.